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# Color reproduction system based on color appearance model and gamut mapping

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## ABSTRACT

By the progress of computer, computer peripherals such as color monitor and printer are often used to generate color image. However, cross media color reproduction by human perception is usually different. Basically, the influence factors are device calibration and characterization, viewing condition, device gamut and human psychology. In this thesis, a color reproduction system based on color appearance model and gamut mapping is proposed. It consists of four parts; device characterization, color management technique, color appearance model and gamut mapping.

**Keywords:** Color appearance model, Gamut mapping

## 1. INTRODUCTION

With the recent advent of color management systems, there provide predictable and consistent color results between different imaging peripherals. We can use them to get more satisfactory color quality than past. Because color is pervasive across media, some unresolved issues have produced. The ICC Processing Model assumes that the Profile Connection Space represents a perfect reproduction. It consists of the ideal reference viewing conditions, perfectly reflecting and unlimited gamut of colorants. In practical application of cross media reproductions, a reproduction will look exactly the same as original image only if both have the same XYZ values for the white point, the two media have similar surface characteristics and are observed under similar viewing conditions, and the reproduction medium can produce all the colors present in the original. So it is important to consider these factors to get good reproduction results.

For these reasons above, we want to develop a color reproduction system that can make sure the color consistent and provide predictable color results between different media. In addition, we hope our application can reproduce more consistent image without measuring instruments. So we use Microsoft Image Color Management (ICM) technique to solve media differences, without using any measuring instruments.

As far as color reproduction is concerned, we may take a deep insight of this problem by dividing it into several parts. They are described as followings:

### 1.1 Device calibration and characterization

Device calibration is the setting of the imaging device to a known state. Calibration ensures that the device is producing consistent results, both from day to day and from device to device. Device characterization defines the relationship between the device color space and the CIE system of color measurement [1]. There are three main approaches to device characterization: physical modeling, empirical modeling and exhaustive measurement. For physical modeling of imaging devices, it involves building mathematical models that relate the calorimetric coordinates of the input or output image elements to the signals used to drive an output device or the signals originating from an input device. For empirical modeling of imaging devices, it involves collecting a fairly large set of data and then statistically fitting a relationship between device coordinates and calorimetric coordinates. For exhaustive measurement of imaging devices, it involves exhaustive measurement of the output for a complete sampling of the device's gamut. But it has a disadvantage that large number of measurements must be made.

Different types of calorimetric measurements are required for the characterization of various imaging devices. For CRT monitor, an overview of alternative display technologies can be found by Jackson [2] and Budin [3]. Beside Berns [4] provide further details on the measurement and characterization of CRT displays. For scanner and digital cameras, the colorimetric calibration and characterization of input devices have been described by Rodriguez and Stockham [5]. For

printers and other output devices, Yule and Nielsen [6] proposed the modified version of Neugebauer Equation with using a LUT between the digital values and measured density.

## 1.2 Color Appearance Model

In order to solved the problem of mismatch between the output as a printer and that of a monitor. Before 1990, the work of color reproduction focused on the consistency of calorimetric measurements between different media [7,8]. However, this type of research did not consider the effect of illumination and can not solve the problem of cross-media image reproduction completely. At the same time, some other researches demonstrated that the appearance of color can be affected by not only the color stimulus but also its viewing conditions like reference white, luminance, surrounding and background [9,10,11]. Until now, several color appearance models had been proposed [12,13,14] to predict color appearance for specific conditions. The aim of these color appearance models is to provide consistency and predictable appearance match between different media.

## 1.3 Gamut Mapping

Different devices are capable of producing different range of colors. The range of colors associated with a device is known as its gamut. Gamut mapping is perhaps the most important element in transforming images across media. It is a fairly new topic in the literature.

Stone, Cowan and Beaty [15] investigated both clipping and compressing techniques in XYZ space. Gentile, Walowitt and Allebach [16] compared several methods of gamut mismatch compensation in  $Lu^*v^*$  space. Generally, they preferred clipping in chroma while keeping lightness and hue constant. Parsier [17] performed a study similar to that of Gentle but with hard copy images. He found that, depending on the input image, either of two techniques was preferred. The first preserves lightness and hue while clipping chroma. The second preserves hue while clipping lightness and chroma toward to the (50, 0, 0) point of  $La^*b^*$  space. MacDonald [18] investigated various mapping in the Hunt [19] color appearance space. His preferred method is also simultaneous compression of light and chroma toward a mid-gamut point. Hoshino and Berns [20] looked at lightness mappings in the Hunt color appearance space. They introduced the concept of "soft compression" in which a cut-off point is defined on the axis of interest. Compression takes place only for values above the cut-off. Wolski, Allebach and Bouman [21] investigated three mapping methods which preserve hue while changing lightness and saturation. First, they altered saturation only. Second, they changed lightness only. Third, they simultaneously clip lightness and saturation toward the center of the target gamut. A linear map, proposed by Lamming and Rhodes [22], which to scale and translate the monitor  $L^*$  to the printer range for  $L^*$  is adequate if the image already appears satisfactorily on the monitor. Meyer and Barth [23] suggested a local function that both adapts the lightness scale and provides edge enhancement. Stone and Wallace [24] proposed an approach to non-linearly adjust the image colors in lightness to control the dynamic range, and in chroma to bring overlay saturated colors inside the target gamut. Most gamut mapping methods do not adjust the hue angle. But the gamut mapping method of Ruetz and Brunoe [25] warps hue angle to compensate for Abney effect [25].

## 2. Proposed approach

The proposed color reproduction system can be divided into three parts; color management technique, color appearance model and gamut mapping. Since the color space representation of each device is different, we must transform the different color space into a device independent color space. This is so-called color space transformation. In order to get more accuracy XYZ values, we using Microsoft ICM 2.0 API functions to transform color space between different device. In addition, the Microsoft ICM 2.0 API functions also control the input and output of different devices. After transformation, the color appearance model will be performed. The XYZ data are transformed via the color appearance model into perceptual LCH coordinates, using the parameters that define the monitor viewing conditions. For gamut mapping model, the LCH image will be modified by compressing the colors that are outside the printer gamut onto the boundary of the gamut. After gamut mapping model, the modified LCH image is then transformed via the inverse color appearance model back into XYZ, using the parameters that define target print viewing conditions. Finally, the XYZ image is converted to CMYK ink values and printed out via printer profile using the Microsoft ICM 2.0 API functions. According to these processes, we can compare the image that printed out with that showed on monitor.

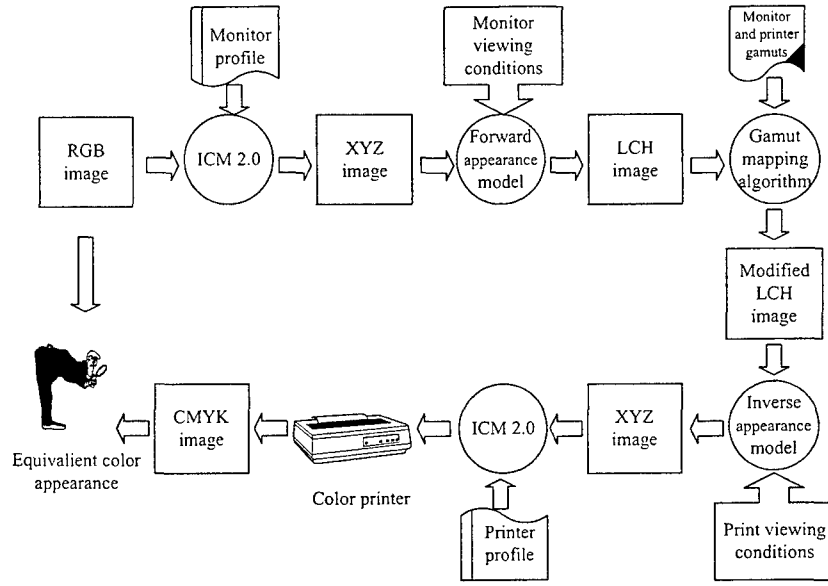


Figure 1. System overview

## 2.1. RLAB model

RLAB model was proposed by Fairchild and Berns [27] for cross media image reproduction application. It evolved from studies of chromatic adaptation; fundamental CIE colorimetry and practical implications in cross media image reproduction. The concept of RLAB is to take advantage of the good spacing under daylight and familiarity of the CIELAB space, while improving its applicability to non-daylight illuminants. It can be used to calculate correlates of lightness, chroma, saturation and hue, but it can not be used to predict brightness or colorfulness. For input data of the RLAB model include the relative tristimulus values of the test stimulus (XYZ) and the white point ( $X_n$ ,  $Y_n$ ,  $Z_n$ ), the absolute luminance of a white object in the scene, the relative luminance of the surround (dark, dim, average) and a decision on whether discounting-the-illuminant is taking place. The forward implementation of RLAB model is described as following. One begins with a conversion from CIE tristimulus values ( $Y=100$  for white) to fundamental tristimulus values with

$$\begin{bmatrix} L \\ M \\ S \end{bmatrix} = M \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} \quad M = \begin{bmatrix} 0.3897 & 0.6890 & -0.0787 \\ -0.2298 & 1.1834 & 0.0464 \\ 0.0 & 0.0 & 1.0000 \end{bmatrix}$$

(1)

The next step is the calculation of the A matrix that is used to model the chromatic-adaptation transformation. The A matrix represents von Kries adaptation coefficients that are applied to the cone responses the test stimulus (LMS). The A matrix can be calculated by following Equations.

$$A = \begin{bmatrix} a_L & 0.0 & 0.0 \\ 0.0 & a_M & 0.0 \\ 0.0 & 0.0 & a_S \end{bmatrix} \quad a_L = \frac{P_L + D(1.0 - p_L)}{L_n} \quad a_M = \frac{p_M + D(1.0 - p_M)}{M_n} \quad a_S = \frac{p_S + D(1.0 - p_S)}{S_n}$$

(2)

Where  $Y_n$  is the absolute adapting luminance. The cone response terms with  $n$  subscripts ( $L_n$ ,  $M_n$ ,  $S_n$ ) refer to values for the adapting stimulus derived from relative tristimulus values. The  $D$  factor allows various proportions of cognitive discounting-the-illuminant. The adjustable  $D$  parameter for media in RLAB model shown in Table 1.

$$P_L = \frac{(1.0 + Y_n^{1/3} + l_E)}{(1.0 + Y_n^{1/3} + 1.0/l_E)} \quad P_M = \frac{(1.0 + Y_n^{1/3} + m_E)}{(1.0 + Y_n^{1/3} + 1.0/m_E)} \quad P_S = \frac{(1.0 + Y_n^{1/3} + s_E)}{(1.0 + Y_n^{1/3} + 1.0/s_E)} \quad (3)$$

**Table 1.** The adjustable  $D$  parameter for media in RLAB model

Media	Parameter value
Hardcopy image	1.0
Softcopy image	0.0
Projected transparencies	0.5

$$l_E = \frac{3.0L_n}{L_n + M_n + S_n} \quad m_E = \frac{3.0M_n}{L_n + M_n + S_n} \quad s_E = \frac{3.0S_n}{L_n + M_n + S_n} \quad (4)$$

After the  $A$  matrix is calculated, the tristimulus values for a stimulus color are converted to corresponding tristimulus values under the reference viewing conditions can be obtained by following Equations.

The RLAB coordinates are then calculated using the following Equations.

$$\begin{bmatrix} X_{ref} \\ Y_{ref} \\ Z_{ref} \end{bmatrix} = RAM \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} \quad R = \begin{bmatrix} 1.9569 & -1.1882 & 0.2313 \\ 0.3612 & 0.6388 & 0.0 \\ 0.0 & 0.0 & 1.0000 \end{bmatrix}$$

$$\begin{aligned} L_R &= 100 (Y_{ref})^\sigma \\ a_R &= 430 [(X_{ref})^\sigma - (Y_{ref})^\sigma] \\ b_R &= 170 [(Y_{ref})^\sigma - (Z_{ref})^\sigma] \end{aligned} \quad (5)$$

$L_R$  represents an achromatic response analogous to CIE  $L^*$ . The red-green chromatic response is given by  $a_R$  (analogous to CIELAB  $a^*$ ) and yellow-blue chromatic response is given by  $b_R$  (analogous to CIELAB  $b^*$ ). For the input parameter  $\sigma$ , it represents the relative luminance of the surround. Its corresponding values are shown in Table 2.

**Table 2.** The adjustable  $\sigma$  parameter for surrounds in RLAB model

Surrounds	Parameter value
Average surrounds	1/2.3
Dim surrounds	1/2.9
Dark surrounds	1/3.5

## 2.2. Finding gamut of printer

Before doing gamut mapping, we must know the gamut of printer. So we print the patches by EPSON stylus color printer and use the standard of ISO 12642 [9] that defines a color palette consisting of 928 combinations of cyan, magenta, yellow and black ink values. After printing, we get the  $L^*a^*b^*$  values of patches by X-Rite 938 spectrophotometer.

Two sets of ink values are specified which span, with differing intervals, the color space defined by combinations of cyan, magenta, yellow and black dot area percentages. The basic data set, which is a subset of the extended data set, shall be the default set in the absence of any other information; the extended data set (or subsets of the ink value data set) may be used if specified. The data are defined as digital data and are not the printed image values (or sets of separations). However, the colorimetric values needed to produce the color characterization data file may be determined by printing images which have been made from films containing halftone values corresponding to the values in the ink value data set. For example, it can be mapped the value from 100 to 255 for four colors individual.

### 2.2.1 Mapping Lightness

The  $L^*$  value represented the lightness in the  $L^*a^*b^*$  system. In absolute terms, monitors are much more dim than printed pages under normal viewing conditions. The darkest black printable may be lighter (under some given illumination) than the brightest light given off by a monitor. Therefore, it is not the absolute lightness but some relative measure that needs to be considered. In the  $L^*a^*b^*$  system, lightness is measured relative to the brightest achromatic color. When transformed to  $L^*$  values, the point corresponding to "white" is always  $L^*=95$ . However, the black point is in different position relative to the white point on different devices. Typical values for monitor black are  $L^*=2$  or 3. For a printer black, we set the values as high as  $L^*=35$  according our experiment.

$L^*$  axis is linearly scaled and transformed so that the  $L^*$  value for black on input is equal to or slightly less than the minimum  $L^*$  value that is black on output. Using a value less than the true black value means that the darkest colors are projected to a point on surface of the destination gamut. This will produce images with improved contrast compared to exactly matching the black values, at the cost of detail in the dark regions. Image that is not very dark tends not to lose much detail using this method. With very dark images, the black point should be matched exactly so that minimum detail is lost. Note that a printer's gamut is much more narrow around the black point than the monitor's gamut, so some compression of the colors in the dark area is inevitable.

### 2.2.2 Mapping Hue Angle

In most of gamut mapping methods, none of them change the hue angle. More particularly, region of pure yellow colors for the printer falls into a very narrow range of the printer gamut. The range of monitor yellow colors is greater. Because the range of pure yellow for printer colors is so narrow that a user typically obtain a greenish-yellow rather than the desired pure yellow colors. Thus the yellow region is widened. Conveniently, yellow widening is obtained through hue angle warping [28] as follows :

$$\begin{aligned} \text{For hue angle between } 87^\circ \text{ to } 91^\circ: \\ \text{warped angle} = 87 + 1.25 * (\text{ang} - 87) \end{aligned} \quad (6)$$

$$\begin{aligned} \text{For hue angle between } 97^\circ \text{ to } 112^\circ: \\ \text{warped angle} = 92 + 0.5 * (\text{ang} - 97) \end{aligned} \quad (7)$$

$$\begin{aligned} \text{For hue angle between } 97^\circ \text{ to } 112^\circ: \\ \text{warped angle} = 92 + 0.5 * (\text{ang} - 97) \end{aligned} \quad (8)$$

$$\begin{aligned} \text{For hue angle between } 112^\circ \text{ to } 132^\circ: \\ \text{warped angle} = 99.5 + 1.25 * (\text{ang} - 112) \end{aligned} \quad (9)$$

For hue angle between  $132^\circ$  to  $147^\circ$ :

$$\text{warped angle} = 124.5 + 1.5 * (\text{ang} - 132) \quad (10)$$

where ang is the hue angle

### 2.2.3 Mapping Chroma

The simplest form of chroma compression projects all out-of-gamut values to the surface of the target gamut. So we replaced the out-of-gamut point with the point that is nearest it and on the border of the curve of gamut. This method is shown in Figure 2. Compressing chroma along lines of constant hue angle provides a method for mapping such an image gamut into a printer gamut without changing the hue, within the limits of the hue definition for uniform color space.

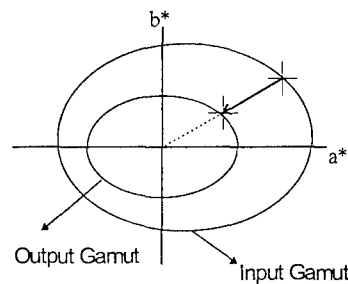


Figure 2. The method of mapping chroma

## 3. Experiment results

The printer used in this experiment is EPSON Stylus COLOR Ink jet printer. Although the maximum resolution of the printer is 720 dpi, only 360 dpi is used to implement the algorithm. We use the standard of ISO 12642 that defines a color palette consisting of 928 combinations of cyan, magenta, yellow and black ink values. Therefore, 928 color patches are printed and then measured by spectrophotometer of X-Rite 938 under  $D_{65}$  illuminant. The data are recorded as CIELAB values. The results were shown in Figure 3, 4 and 5.

The datum we measured is used to find the boundary of printer gamut. The data set can be used to do gamut mapping. Besides, we need to print the nine reference colors of cyan, magenta, yellow, red, green, blue, mixed-color (CMY), black and white (no ink), and measure the actual CIELAB values for these colors.

For the color appearance model, we use the RLAB model in our system. The experiment is conducted in a dim surrounding. Since the aim of our method is want the reproduced images with the original images on monitor more closely. In RLAB model, we set the D factor equal to 1.0 for hardcopy images and 0.0 for softcopy images.

Finally, Reproduced images by printer are compared with original images that displayed on NEC multiSync 5FGp CRT. Twenty observers took part in the experiment. Most observers are in the field of image processing. They ranged in age from 23 to 28 years old. We use the IT8 standard graphics images to test our algorithm. Each image will be printed by three different methods including our proposed method.

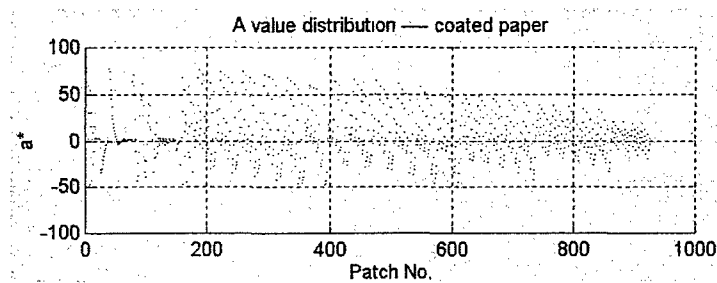


Figure 2. The value of  $a^*$

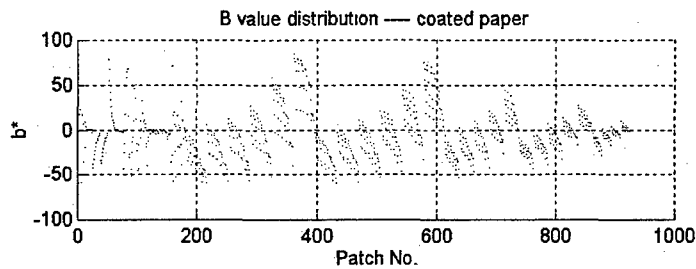


Figure 3. The value of  $b^*$

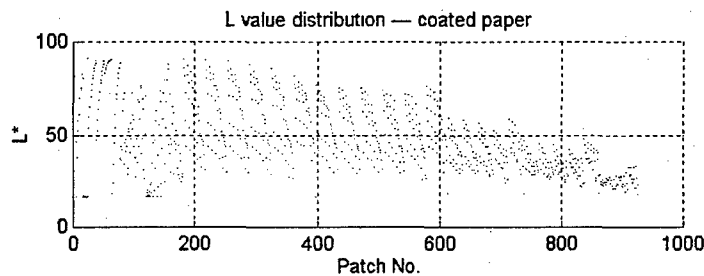


Figure 4. The value of  $L$

### 3.2 Comparison of images

In our experiments, three ANSI IT8 standard images are used as the tested images. They consist of format with true color. The first is gloomy, and the contrast of color between light and dark is strong. The color of second image is rich, and it can test color reproduction of our system. The third image consists of most light colors. It is tested for burnish of the metal and gray color rendering. The contents and characteristics of the testing images shown in Table 3.

Moreover, all images are printed by using different four kinds of method. Because we can not present the same visual effect for tested images on monitor as the images on papers. First, we use Fujix pictography 3000 to print the images as the reference image. Second, the tested images are printed by Kodak Imaging. Third, we printed the tested images by Kodak Imaging with using ICM 2.0. Finally, we use the proposed algorithm to print the images.

The part (a) of each image is printed at 400 dpi by Fujix pictography 3000. The part (b) of each image is printed by Kodak Imaging. The part (c) of each image is printed by Kodak Imaging with using ICM 2.0. The part (d) of each image is printed by our method.

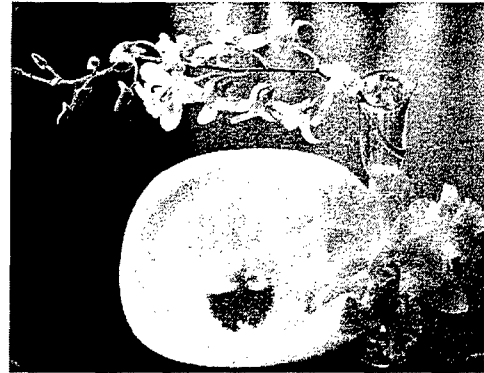


**Table 3.** The contents and characteristics of the testing images

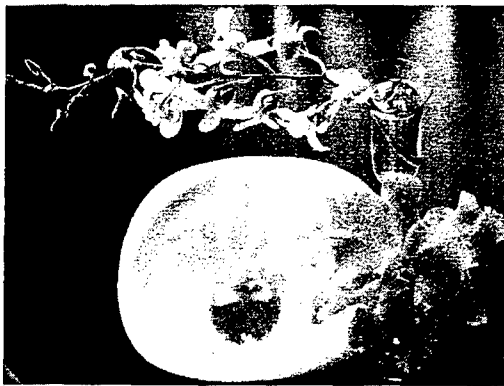
	contents	characteristics
Image #1	orchid	Low Lightness
Image #2	fruits	High saturation
Image #3	tableware	High Lightness



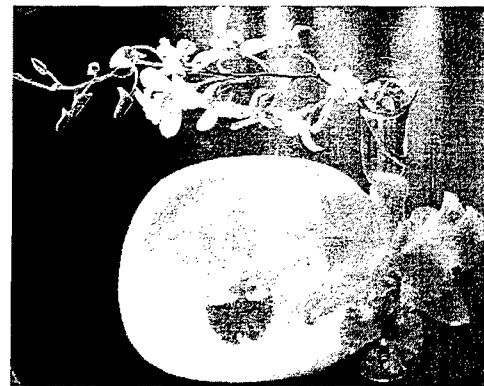
(a)



(b)

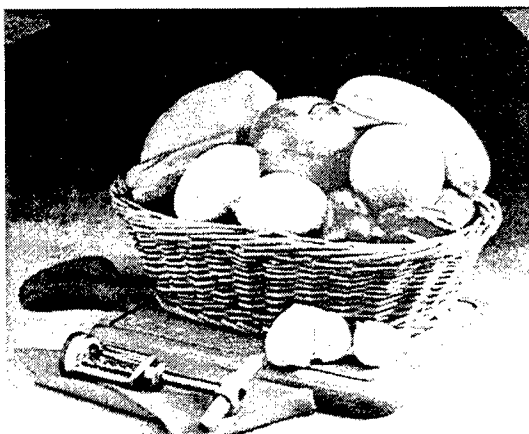


(c)

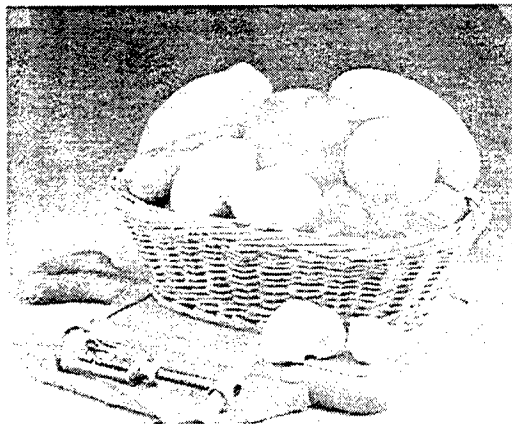


(d)

**Figure 5.** Sample image #1



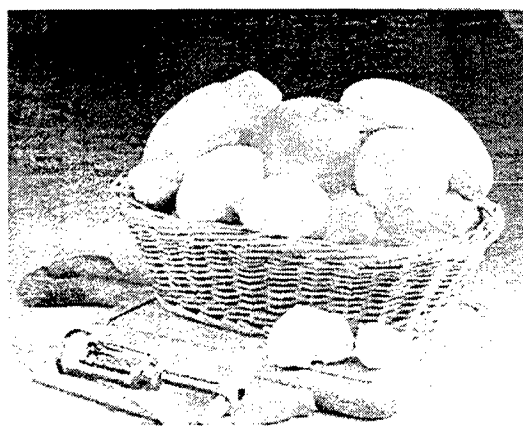
(a)



(b)



(c)



(d)

Figure 6. Sample image #2

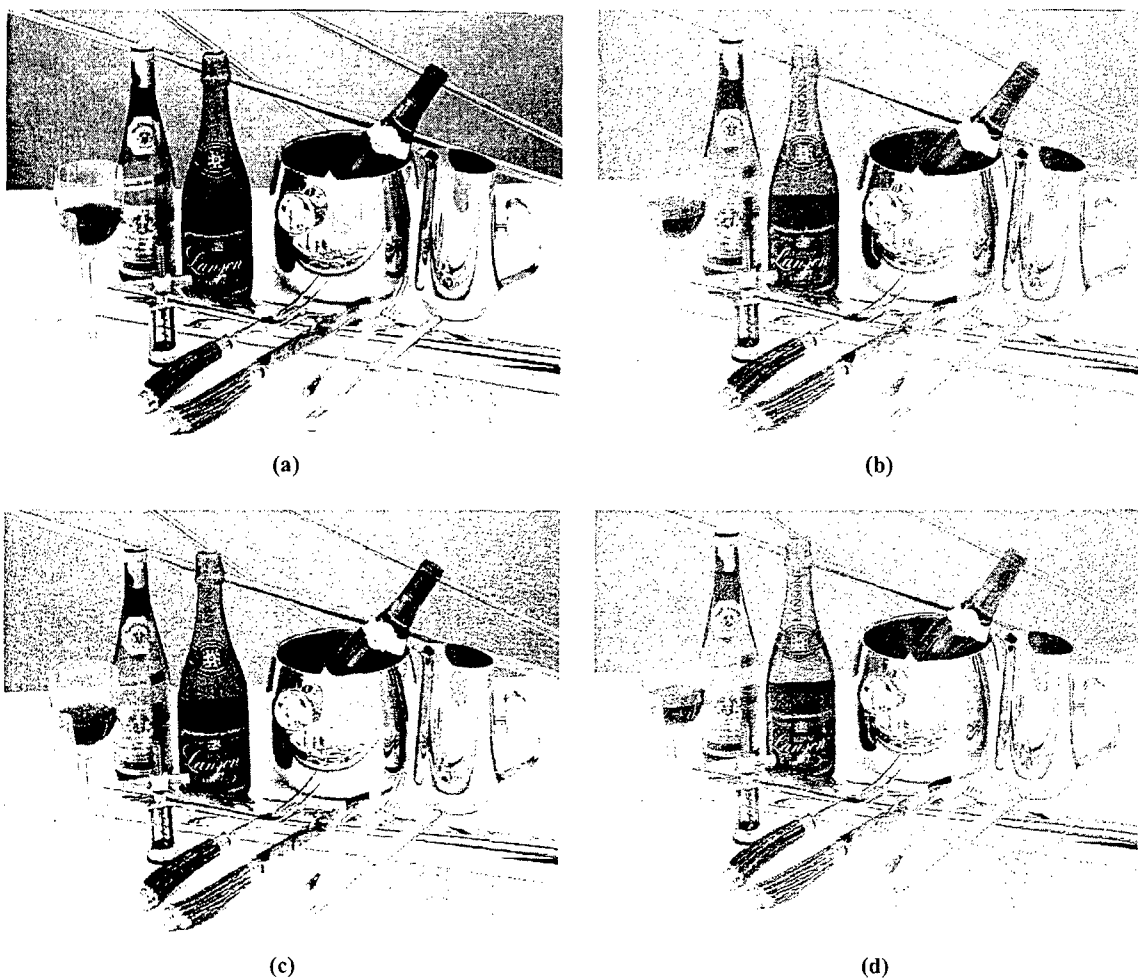


Figure 7. Sample image #3

Taking a global view of these three images, the color is more like the display of monitor when they were printed by our method. The result has shown in Table 4. For the tested image #1, There are almost seventy-percent observers to decide that printed by our method is more consistent than others are. For the tested image #2, there are only forty observers to decide our method is better than others are. For the tested image #3, most of observers to decide our method have best color reproduction. For all of the tested images, no body to decide that printed by Imaging is better than others.

Table 4. Comparison result

	Printed by Imaging	Printed by Imaging with using ICM	Printed by our method
Image #1	0	6	14
Image #2	0	12	8
Image #3	0	5	15

#### 4. Conclusion

Since the computer peripherals become cheaper and more popular, it is important for us to improve consistence of cross media color reproduction. However, effective color reproduction remains a very complex process and depends on many factors, not only device behavior but also human visual perception and the viewing conditions in which an image is seen.

In our experiments, the color images implemented by our method have better color reproduction. Besides, our method can provide most of people to get consistent and accurate color reproduction without using "high end" peripherals and measured instruments.

There are still some the future work to be done. Since color appearance models are still the topic of research for color science. How to find the best performance of color appearance models in considering practical viewing conditions is yet to achieve. Second, if the better model of gamut mapping is found, the color reproduction system will be more perfect.

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